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# TESTS OF AN ADJUSTABLE-AREA EXHAUST NOZZLE FOR JET-PROPULSION ENGINES

By E. C. Wilcox

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

# TESTS OF AN ADJUSTABLE-AREA EXHAUST NOZZLE FOR JET-PROPULSION ENGINES

By E. C. Wilcox

## SUMMARY

Tests were conducted on a 1600-pound-thrust centrifugal-flow-type turbojet engine equipped with an NACA designed adjustable-area exhaust nozzle and with a series of fixed-area nozzles of various throat diameters. The effective area range obtained on the variable-area nozzle corresponded to the area change accompanying a variation in fixed-area-nozzle throat diameter of from 11.1 to 12.6 inches.

A comparison of the performance data of the engine obtained in the two series of tests indicated that the adjustable-area nozzle was as efficient as the fixed-area nozzles tested.

## INTRODUCTION

In their present stage of development, it is advantageous to provide existing jet-propulsion engines with a method of augmenting their power output for take-off, climb, and during combat when sudden bursts of power may be necessary. Investigations of methods of providing this momentary power increase indicated the desirability of a variable-area exhaust nozzle. When used in conjunction with an augmentation scheme, an adjustable-area exhaust nozzle should permit the turbine-discharge temperature, which is a measure of the turbine-bucket temperature, to be maintained at its normal value. An adjustable-area exhaust nozzle is also valuable for normal operation because the engine may be operated at maximum efficiency or maximum power output, over a wide range of engine inlet temperatures and pressures and airplane speeds, by adjusting the discharge nozzle area.

Certain jet engines are equipped with an adjustable-area discharge nozzle of the following type: The inner exhaust cone, behind the turbine, is equipped with a movable conical end section. This end section extends beyond the circular nozzle opening and thus provides an annular discharge area, which may be varied by moving the conical end section along the axis of the engine. The adjustable-area exhaust nozzle described in this paper is intended for use on jet engines not equipped with a means of varying the discharge nozzle area.

This report presents performance data obtained during April 1945 at the NACA Cleveland laboratory on a 1600-pound-thrust centrifugal-flow-type turbojet engine equipped with an NACA designed adjustable-area exhaust nozzle. In order to obtain a basis of comparison, performance data were also obtained on the engine equipped with straight-sided fixed-area nozzles of various throat diameters.

## DESCRIPTION OF APPARATUS

The adjustable-area exhaust nozzle used for the test reported herein (see fig. 1) consists of a spherical nozzle with a circular discharge area equipped with two adjustable flaps. Both the nozzle and the flaps are so made that their surfaces lie on concentric spheres, thus allowing relative motion between the flaps and the nozzle without changing the radial clearance between them. Inasmuch as relatively large clearances are used between the flaps and the nozzle to prevent sticking at high operating temperatures, thin metal sealing strips (fig. 1) are provided to prevent leakage. The flaps are adjusted by a screw-operated linkage. The linkage was designed only for test purposes and is not intended for use in flight installations. The nozzles used for comparison (fig. 2) were straight-sided fixed-area nozzles with throat diameters varying from 11.5 to 13.5 inches and with equal angles of taper.

The nozzle tests described in this report were conducted with the nozzle mounted on a 1600-pound-thrust centrifugal-flow-type turbojet engine. The installation of the adjustable-area nozzle on the jet engine is shown in figure 3.

## TEST PROCEDURE

In order to adjust the nozzle through its entire range, that is, from the full-closed to the full-open position, 24 turns of the adjusting screw were required. Tests were conducted at 0, 6, 12, 18, and 24 turns open. The throat diameters of the fixed-area nozzles used to obtain a basis for comparison were 11.5, 12,0, 12.5, 13.0, and 13.5 inches.

Tests were conducted in the following manner: For a given position of the adjustable nozzle or for a given fixed-area nozzle size, performance data were obtained at various rotor speeds ranging from 12,000 rpm to either 16,500 rpm or to the speed corresponding to the maximum allowable tail-pipe gas temperature. This procedure was repeated for all fixed-area nozzle sizes and for several positions of the adjustable nozzle. All tests were run on the same day in order to maintain relatively constant inlet conditions.

## RESULTS AND DISCUSSION

The performance data obtained as observed and as corrected to standard sea-level conditions at engine inlet (519° R and 14.7 lb/sq in. absolute) are presented in table I.

The corrected static thrust, fuel flow, and tail-pipe gas temperature are shown as functions of corrected rotor speed in figures 4, 5, and 6, respectively. Part (a) of each figure presents data for various positions of the adjustable nozzle and part (b), for various throat diameters of the fixed-area nozzles.

The data presented in figures 4 and 5 are cross-plotted in figure 7 to provide curves of static thrust against fuel flow at several constant rotor speeds for both the adjustable-area nozzle and the fixed-area nozzles. Obviously, the higher the thrust produced at a given fuel flow and rotor speed, the more efficient the nozzle. The discharge area of the adjustable nozzle changes from circular in the full-open position to elliptical in the full-closed position. There was a possibility that this elliptical shape might incur more losses than the circular but figure 7 indicates that the adjustable-area nozzle, in all positions, was as efficient as the fixed-area nozzles tested.

Curves of static thrust against tail-pipe gas temperature at several constant rotor speeds are presented in figure 8 (cross plot from figs. 4 and 6) for both the adjustable-area nozzle and the fixed-area nozzles. Because the measurements of tail-pipe temperature were less accurate than the fuel-flow data, any slight discrepancy between the curves of figures 7 and 8 may be attributed to experimental error; both figures 7 and 8, however, indicate that the adjustable-area nozzle was as efficient as the fixed-area nozzles tested.

Figure 9 presents the equivalent throat diameter of a fixed-area nozzle corresponding to a given position of the adjustable-area exhaust nozzle. This curve was obtained from the data of figure 5. The fuel flow for a given rotor speed and fixed-area-nozzle diameter was found from figure 5(b); with the same rotor speed and fuel flow, the adjustable-nozzle position corresponding to the given nozzle diameter was found from the data of figure 5(a). This procedure was repeated until a complete curve was obtained. Although the curve is drawn for a constant rotor speed of 14,000 rpm, the variation with rotor speed is slight. By means of the adjustable-area nozzle tested, an effective-area range could be obtained corresponding to the area change accompanying a variation in fixed-area-nozzle throat diameter from 11.1 to 12.6 inches. Although the area range possible for a nozzle of this type is relatively fixed for a given tail-pipe diameter, the upper and lower area limits may be readily varied by altering the design of the nozzle and flaps. (See fig. 1.)

## SUMMARY OF RESULTS

A comparison of the performance of a 1600-pound-thrust centrifugal-flow-type turbojet engine when equipped with an NACA designed adjustable-area exhaust nozzle and when equipped with a series of fixed-area nozzles of various throat diameters indicates that the adjustable-area nozzle is as efficient as the fixed-area nozzles tested.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, August 16, 1945.

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I – PERFORMANCE OF 1600-POUND-THRUST CENTRIFUGAL-FLOW-TYPE TURBOJET ENGINE EQUIPPED WITH AN ADJUSTABLE-AREA EXHAUST NOZZ
AND PERFORMANCE WITH FIXED-AREA NOZZLES OF VARIOUS THROAT DIAMETERS

[As observed and as corrected to standard sea-level conditions (14.70 lb/sq in. abs. and 519° R) at engine inlet]

| Reading | Barometric pressure (lb/sq in. abs.) | Exhaust nozzle: Fixed-area nozzle-throat diameter (in.) | Exhaust nozzle: Adjustable-nozzle position (turns open) | Engine-inlet total temperature (°R) | | Engine-inlet total pressure (lb/sq in. abs.) | | Rotor speed (rpm) | | Static thrust (lb) | | Fuel flow (lb/hr) | | Indicated tail-pipe gas temperature (°R) | | Air flow (lb/sec) | | Specific fuel consumption (lb)/(hr)(lb-thrust) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Read | Corr. | Read | Corr. | Read | Corr. | Read | Corr. | Read | Corr. | Read | Corr. | Read | Corr. | Read | Corr. |
| A1 | 14.45 | — — — | 0 | 524 | 519 | 14.43 | 14.70 | 12,006 | 11,948 | 725 | 739 | 1105 | 1120 | 1572 | 1557 | 19.3 | 19.8 | 1.524 | 1.516 |
| A2 | | | | 527 | | 14.42 | | 13,037 | 12,938 | 896 | 913 | 1292 | 1307 | 1628 | 1603 | 21.5 | 22.1 | 1.442 | 1.432 |
| A3 | | | | 531 | | 14.43 | | 14,000 | 13,840 | 1082 | 1103 | 1516 | 1528 | 1705 | 1666 | 23.4 | 24.1 | 1.401 | 1.385 |
| A4 | 14.45 | — — — | 6 | 523 | 519 | 14.43 | 14.70 | 11,950 | 11,905 | 670 | 683 | 1002 | 1017 | 1470 | 1459 | 19.9 | 20.4 | 1.496 | 1.489 |
| A5 | | | | 523 | | 14.43 | | 12,997 | 12,948 | 826 | 841 | 1167 | 1184 | 1510 | 1499 | 22.1 | 22.6 | 1.413 | 1.408 |
| A6 | | | | 527 | | 14.42 | | 13,980 | 13,874 | 1001 | 1020 | 1363 | 1379 | 1562 | 1538 | 24.2 | 24.8 | 1.362 | 1.352 |
| A7 | | | | 526 | | 14.41 | | 15,006 | 14,905 | 1221 | 1246 | 1625 | 1647 | 1646 | 1624 | 26.5 | 27.2 | 1.331 | 1.322 |
| A8 | 14.45 | — — — | 12 | 522 | 519 | 14.43 | 14.70 | 11,904 | 11,869 | 618 | 630 | 943 | 958 | 1403 | 1395 | 20.1 | 20.6 | 1.526 | 1.521 |
| A9 | | | | 522 | | 14.42 | | 13,003 | 12,965 | 762 | 777 | 1100 | 1118 | 1430 | 1422 | 23.5 | 24.0 | 1.444 | 1.439 |
| A10 | | | | 523 | | 14.42 | | 14,000 | 13,947 | 922 | 940 | 1270 | 1290 | 1472 | 1461 | 24.8 | 25.3 | 1.377 | 1.372 |
| A11 | | | | 526 | | 14.41 | | 15,016 | 14,915 | 1135 | 1158 | 1500 | 1520 | 1542 | 1521 | 27.2 | 27.9 | 1.322 | 1.313 |
| A12 | | | | 530 | | 14.40 | | 16,009 | 15,843 | 1364 | 1392 | 1788 | 1806 | 1648 | 1614 | 29.3 | 30.2 | 1.311 | 1.297 |
| A13 | 14.45 | — — — | 18 | 523 | 519 | 14.43 | 14.70 | 11,970 | 11,925 | 574 | 585 | 909 | 922 | 1358 | 1348 | 20.5 | 20.9 | 1.584 | 1.576 |
| A14 | | | | 525 | | 14.42 | | 13,007 | 12,932 | 707 | 721 | 1047 | 1061 | 1380 | 1364 | 22.8 | 23.3 | 1.481 | 1.472 |
| A15 | | | | 523 | | 14.42 | | 13,968 | 13,915 | 855 | 872 | 1195 | 1214 | 1412 | 1401 | 24.8 | 25.5 | 1.398 | 1.392 |
| A16 | | | | 526 | | 14.41 | | 15,026 | 14,925 | 1057 | 1078 | 1414 | 1433 | 1480 | 1460 | 27.3 | 28.1 | 1.338 | 1.329 |
| A17 | | | | 528 | | 14.40 | | 15,989 | 15,853 | 1283 | 1310 | 1695 | 1716 | 1578 | 1551 | 29.5 | 30.4 | 1.321 | 1.310 |
| A18 | | | | 529 | | 14.40 | | 16,445 | 16,289 | 1404 | 1433 | 1854 | 1875 | 1637 | 1606 | 30.5 | 31.5 | 1.321 | 1.308 |
| A19 | 14.45 | — — — | 24 | 523 | 519 | 14.43 | 14.70 | 11,966 | 11,921 | 540 | 550 | 893 | 906 | 1342 | 1332 | 20.5 | 21.0 | 1.654 | 1.647 |
| A20 | | | | 523 | | 14.42 | | 13,219 | 12,970 | 675 | 688 | 1022 | 1038 | 1360 | 1350 | 22.8 | 23.4 | 1.514 | 1.509 |
| A21 | | | | 525 | | 14.42 | | 13,990 | 13,909 | 819 | 835 | 1165 | 1181 | 1392 | 1376 | 25.0 | 25.6 | 1.422 | 1.414 |
| A22 | | | | 524 | | 14.41 | | 15,070 | 14,938 | 1014 | 1034 | 1371 | 1392 | 1453 | 1439 | 27.3 | 27.9 | 1.352 | 1.346 |
| A23 | | | | 529 | | 14.40 | | 15,991 | 15,839 | 1243 | 1269 | 1652 | 1670 | 1553 | 1524 | 29.5 | 30.4 | 1.329 | 1.316 |
| A24 | | | | 531 | | 14.40 | | 16,469 | 16,281 | 1366 | 1394 | 1821 | 1838 | 1615 | 1579 | 30.5 | 31.5 | 1.333 | 1.319 |
| B1 | 14.43 | 11.5 | — — — | 528 | 519 | 14.40 | 14.70 | 11,978 | 11,876 | 657 | 671 | 1011 | 1023 | 1490 | 1465 | 19.5 | 20.1 | 1.539 | 1.525 |
| B2 | | | | 528 | | 14.40 | | 12,983 | 12,873 | 810 | 827 | 1172 | 1186 | 1535 | 1509 | 21.5 | 22.2 | 1.447 | 1.434 |
| B3 | | | | 530 | | 14.39 | | 13,976 | 13,831 | 1003 | 1025 | 1379 | 1395 | 1600 | 1567 | 23.6 | 24.4 | 1.375 | 1.361 |
| B4 | | | | 532 | | 14.39 | | 14,974 | 14,791 | 1230 | 1257 | 1662 | 1678 | 1705 | 1663 | 25.6 | 26.5 | 1.351 | 1.335 |
| B5 | 14.43 | 12.0 | — — — | 527 | 519 | 14.40 | 14.70 | 11,972 | 11,881 | 607 | 620 | 958 | 971 | 1425 | 1403 | 19.9 | 20.4 | 1.578 | 1.566 |
| B6 | | | | 526 | | 14.40 | | 12,961 | 12,874 | 742 | 758 | 1098 | 1114 | 1455 | 1436 | 22.0 | 22.7 | 1.480 | 1.470 |
| B7 | | | | 527 | | 14.39 | | 13,986 | 13,880 | 920 | 940 | 1275 | 1293 | 1500 | 1477 | 24.2 | 24.9 | 1.386 | 1.376 |
| B8 | | | | 531 | | 14.38 | | 15,006 | 14,835 | 1137 | 1162 | 1513 | 1529 | 1575 | 1539 | 26.5 | 27.4 | 1.331 | 1.316 |
| B9 | | | | 532 | | 14.38 | | 15,985 | 15,790 | 1386 | 1416 | 1818 | 1835 | 1685 | 1644 | 28.5 | 29.5 | 1.312 | 1.296 |
| B10 | 14.43 | 12.5 | — — — | 525 | 519 | 14.40 | 14.70 | 11,972 | 11,904 | 562 | 574 | 906 | 920 | 1360 | 1344 | 20.3 | 20.9 | 1.612 | 1.603 |
| B11 | | | | 524 | | 14.40 | | 13,005 | 12,943 | 681 | 695 | 1034 | 1051 | 1380 | 1367 | 22.5 | 23.1 | 1.518 | 1.512 |
| B12 | | | | 526 | | 14.39 | | 14,008 | 13,914 | 836 | 854 | 1184 | 1202 | 1415 | 1396 | 24.8 | 25.5 | 1.416 | 1.407 |
| B13 | | | | 527 | | 14.38 | | 15,018 | 14,904 | 1025 | 1048 | 1396 | 1411 | 1480 | 1458 | 27.0 | 27.8 | 1.357 | 1.346 |
| B14 | | | | 530 | | 14.38 | | 15,989 | 15,823 | 1254 | 1282 | 1668 | 1687 | 1575 | 1542 | 29.1 | 30.1 | 1.330 | 1.316 |
| B15 | | | | 532 | | 14.37 | | 16,483 | 16,282 | 1384 | 1416 | 1835 | 1854 | 1645 | 1605 | 30.7 | 31.3 | 1.326 | 1.309 |
| B16 | 14.43 | 13.0 | — — — | 525 | 519 | 14.40 | 14.70 | 11,944 | 11,876 | 504 | 515 | 866 | 879 | 1325 | 1310 | 20.4 | 20.9 | 1.718 | 1.707 |
| B17 | | | | 524 | | 14.40 | | 12,971 | 12,909 | 621 | 634 | 980 | 996 | 1340 | 1327 | 22.6 | 23.2 | 1.578 | 1.571 |
| B18 | | | | 524 | | 14.39 | | 13,976 | 13,909 | 760 | 777 | 1119 | 1138 | 1365 | 1352 | 24.8 | 25.5 | 1.472 | 1.465 |
| B19 | | | | 526 | | 14.38 | | 15,020 | 14,919 | 939 | 960 | 1313 | 1333 | 1425 | 1406 | 27.2 | 28.0 | 1.398 | 1.389 |
| B20 | | | | 528 | | 14.37 | | 15,995 | 15,859 | 1157 | 1184 | 1583 | 1606 | 1520 | 1494 | 29.2 | 30.2 | 1.368 | 1.356 |
| B21 | | | | 531 | | 14.37 | | 16,475 | 16,287 | 1282 | 1311 | 1752 | 1772 | 1585 | 1549 | 30.4 | 31.4 | 1.367 | 1.352 |
| B22 | 14.43 | 13.5 | — — — | 525 | 519 | 14.40 | 14.70 | 11,938 | 11,870 | 465 | 475 | 839 | 852 | 1300 | 1285 | 20.5 | 21.1 | 1.804 | 1.794 |
| B23 | | | | 524 | | 14.40 | | 12,977 | 12,915 | 576 | 588 | 950 | 965 | 1310 | 1298 | 22.7 | 23.3 | 1.649 | 1.641 |
| B24 | | | | 525 | | 14.39 | | 13,980 | 13,900 | 703 | 718 | 1080 | 1097 | 1335 | 1320 | 25.0 | 25.7 | 1.536 | 1.528 |
| B25 | | | | 526 | | 14.38 | | 15,033 | 14,932 | 869 | 888 | 1267 | 1286 | 1390 | 1372 | 27.3 | 28.1 | 1.458 | 1.448 |
| B26 | | | | 529 | | 14.37 | | 15,999 | 15,847 | 1072 | 1097 | 1532 | 1552 | 1490 | 1462 | 29.5 | 30.4 | 1.429 | 1.415 |
| B27 | | | | 530 | | 14.37 | | 16,493 | 16,321 | 1192 | 1219 | 1710 | 1731 | 1560 | 1528 | 30.5 | 31.5 | 1.435 | 1.420 |

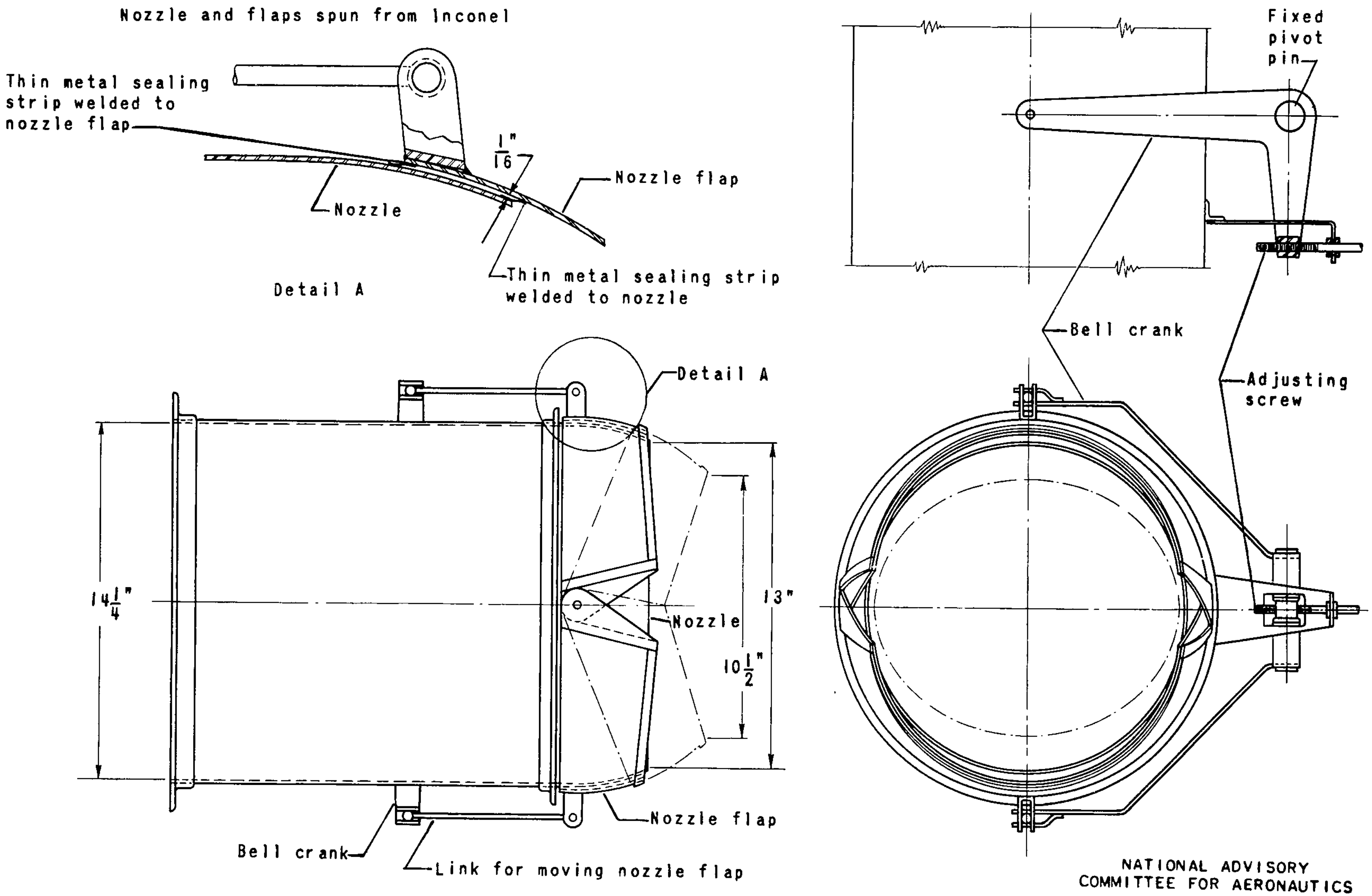
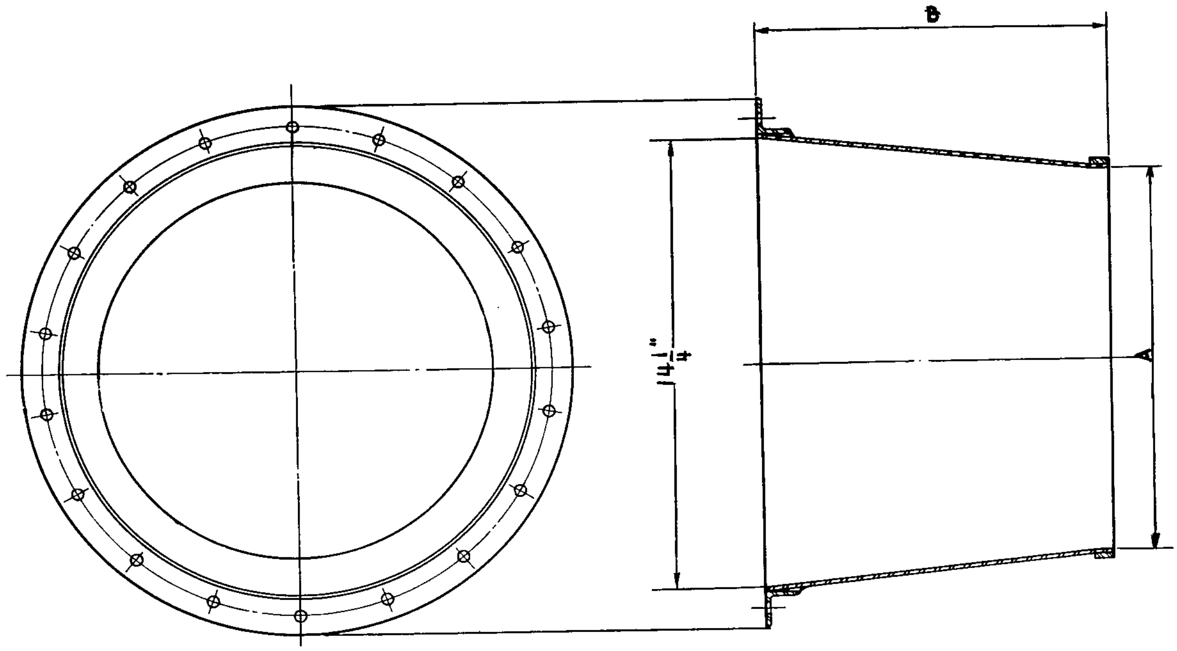



Figure 1. - Details of NACA designed adjustable-area nozzle and operating linkage.




| Reading | A(in.) | B(in.) |
|---|---|---|
| B1-B4 | 11.5 | 12.5 |
| B5-B9 | 12.0 | 10.3 |
| B10-B15 | 12.5 | 8.0 |
| B16-B21 | 13.0 | 5.7 |
| B22-B27 | 13.5 | 3.4 |

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Figure 2. - Details of fixed-area nozzles.

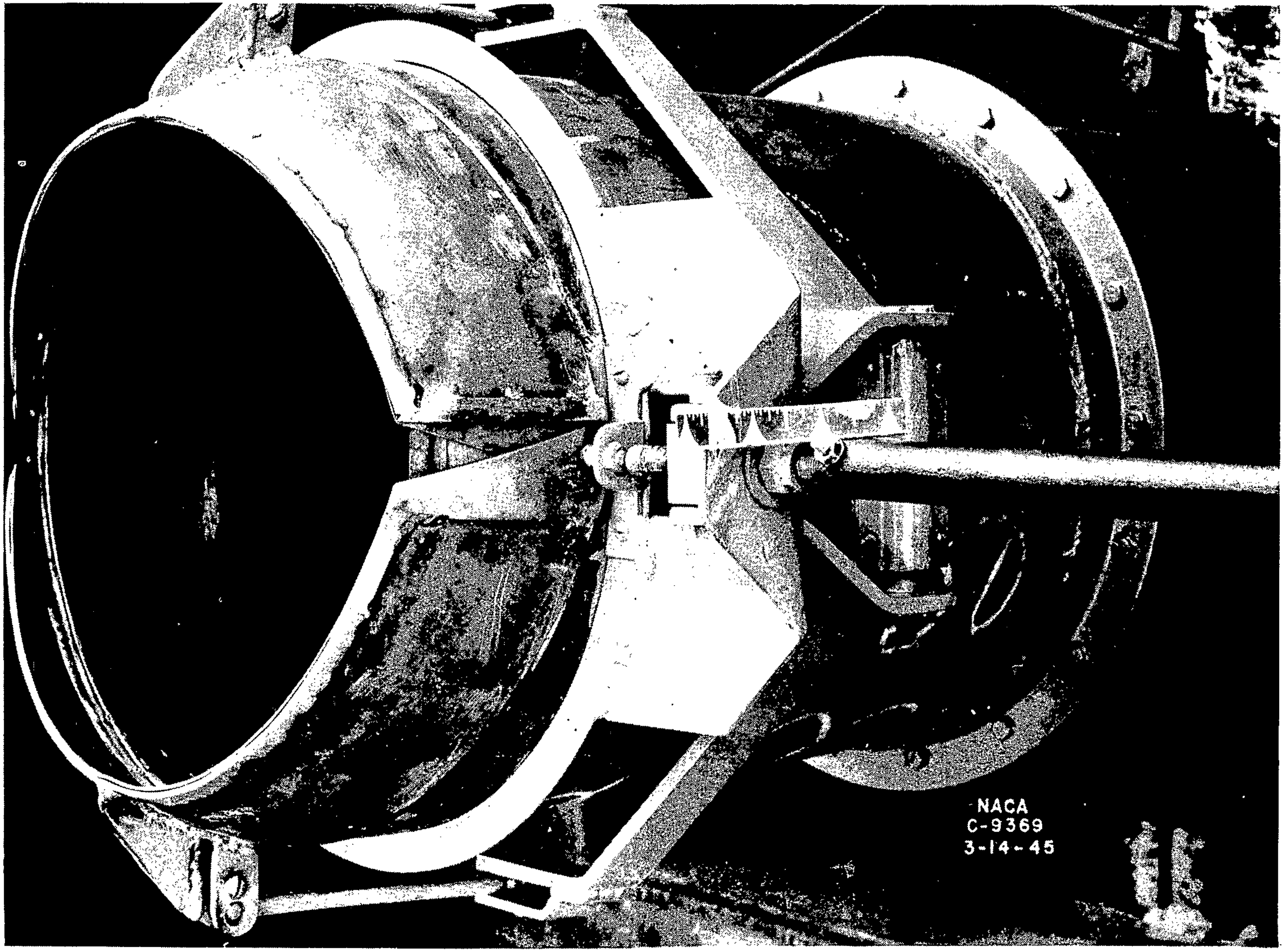
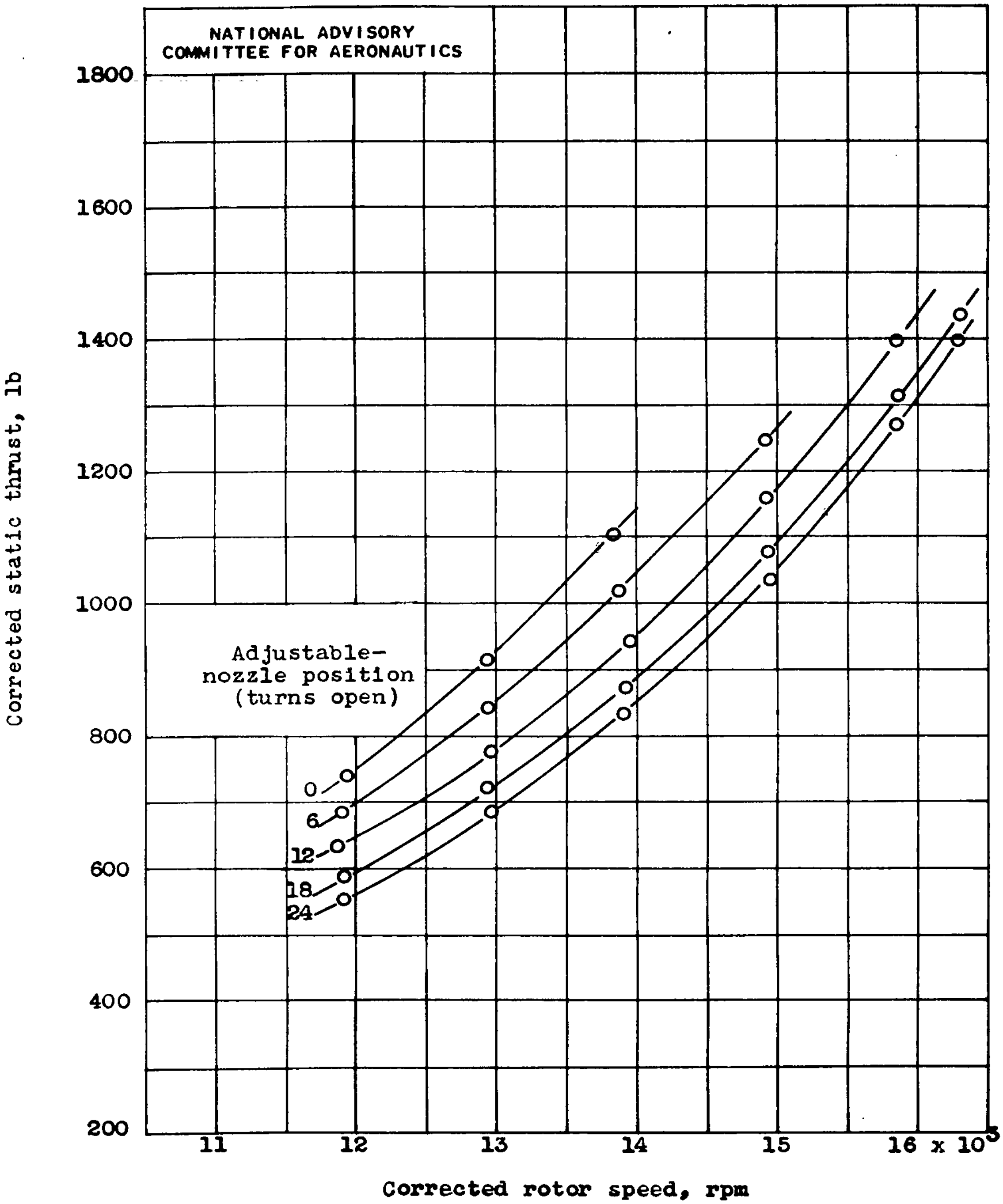
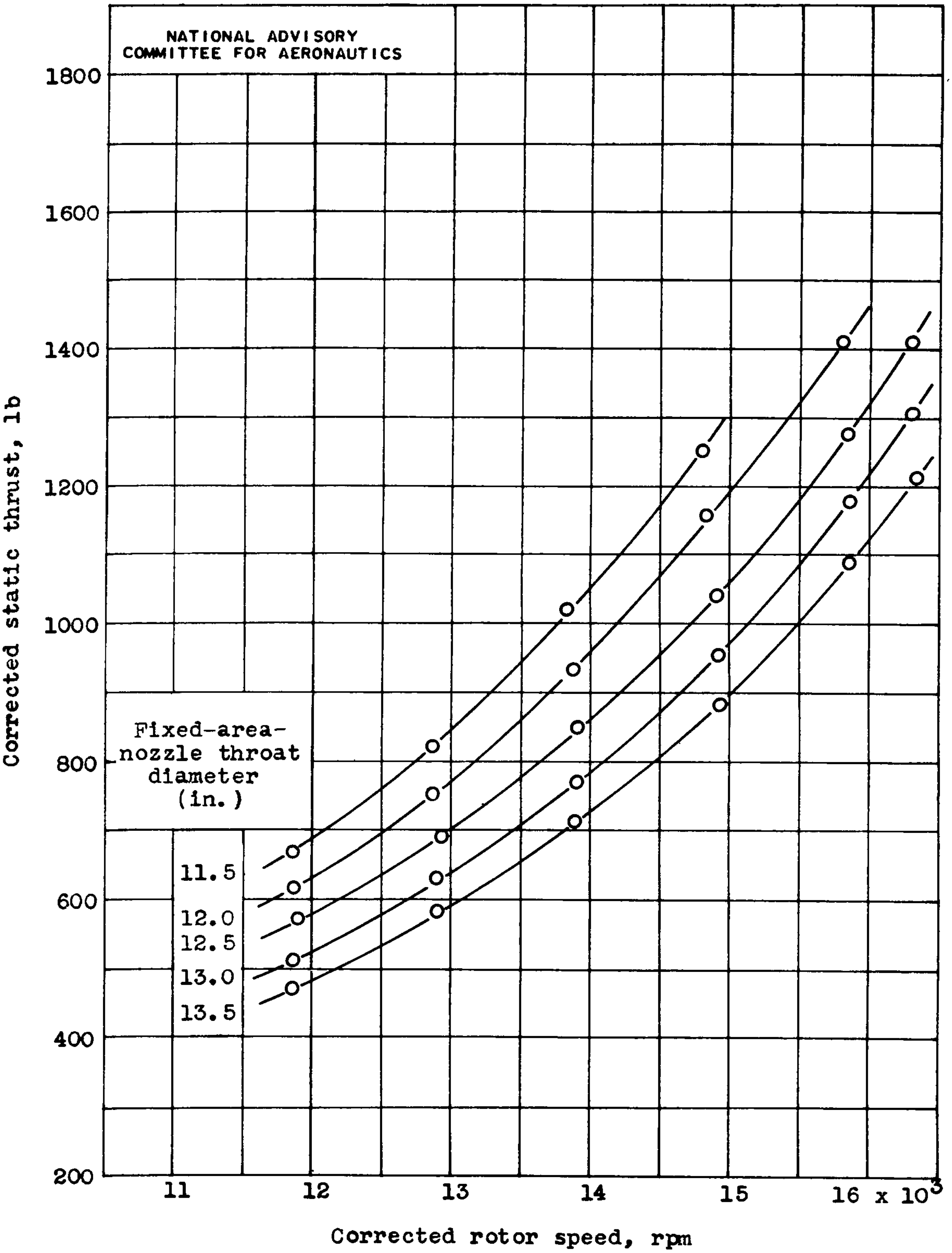



Figure 3. - Installation of adjustable-area nozzle on jet-engine tail pipe.



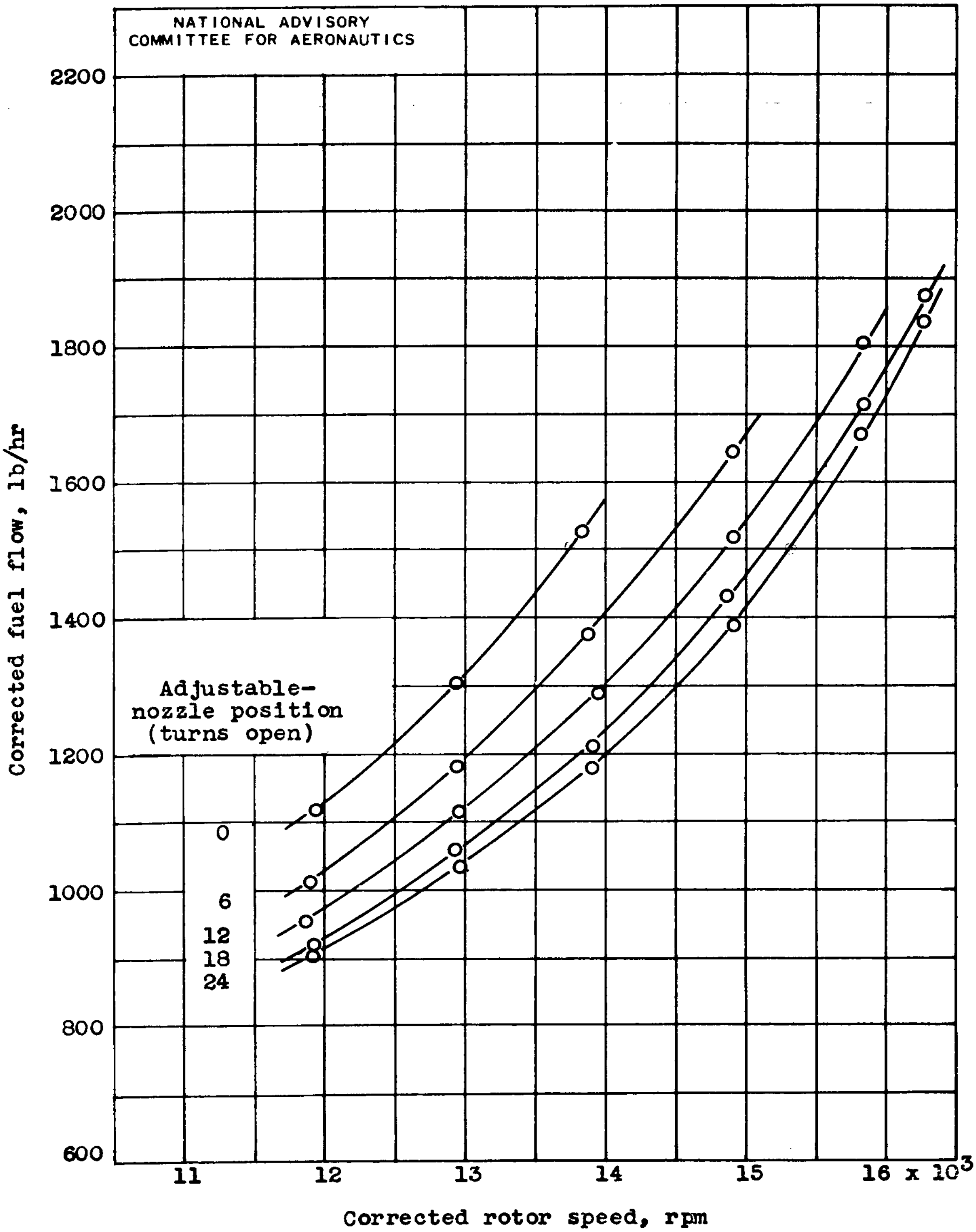

(a) Adjustable-area exhaust nozzle.

Figure 4. - Variation of thrust with exhaust-nozzle area and rotor speed.



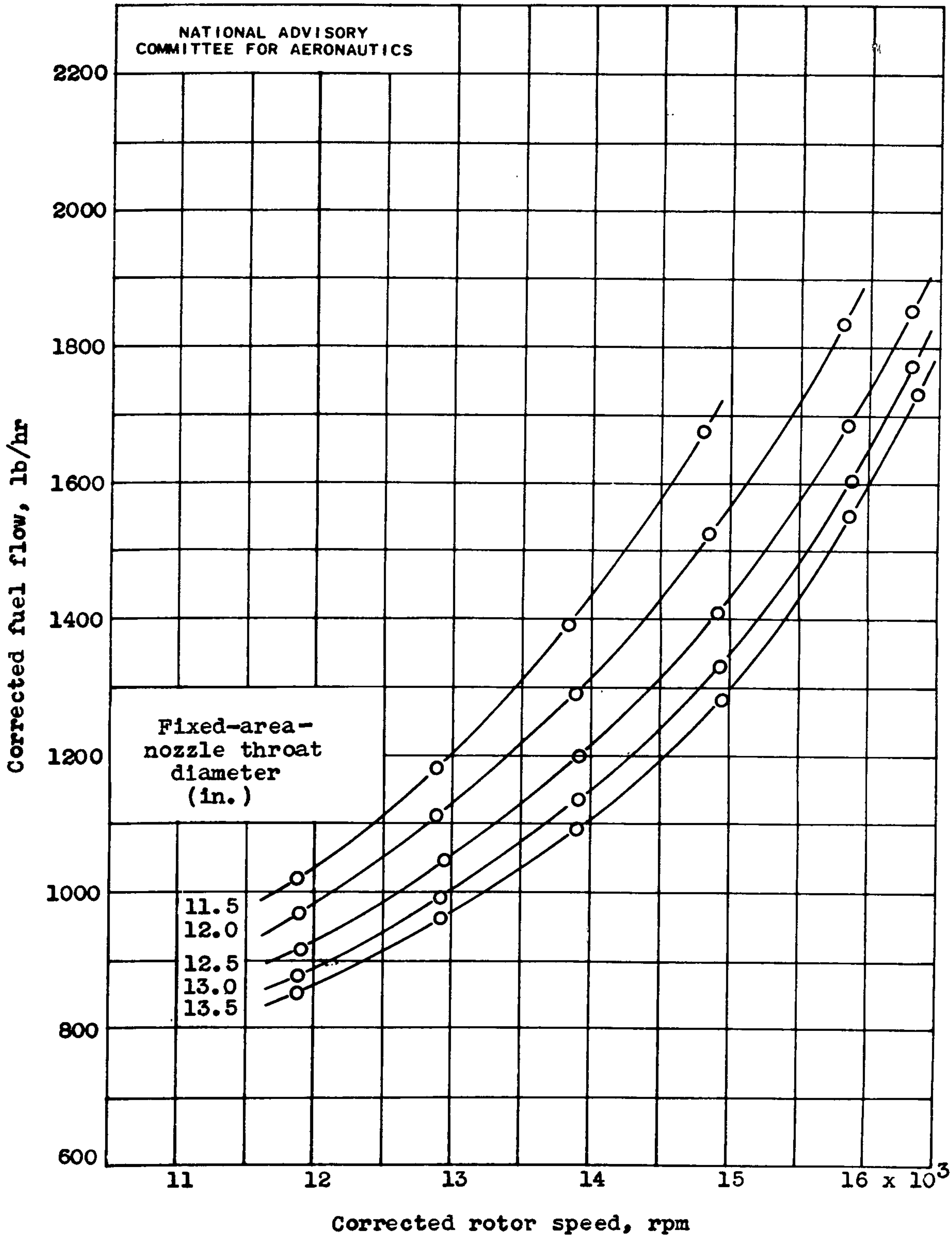

(b) Fixed-area nozzles.

Figure 4. - Concluded.



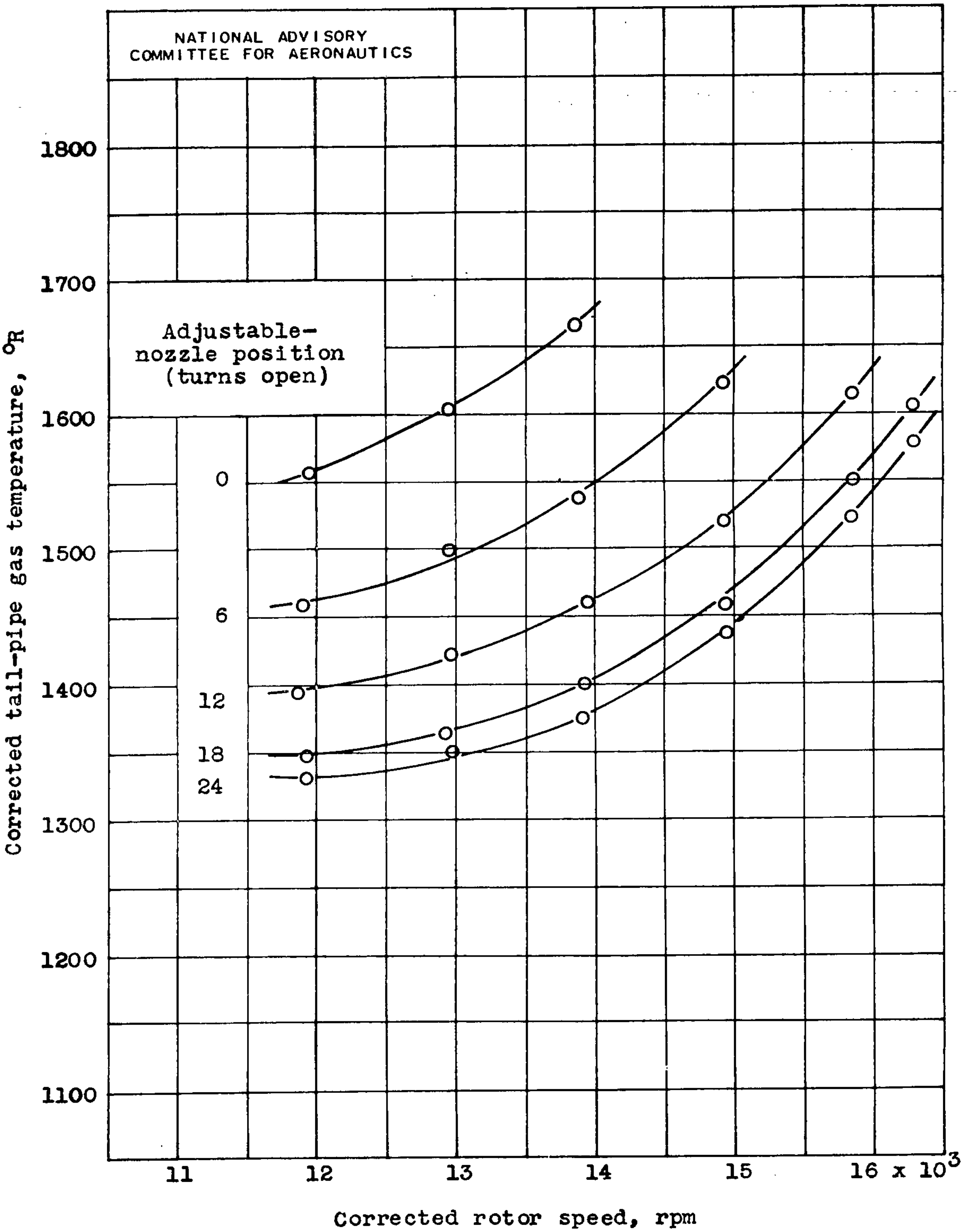

(a) Adjustable-area exhaust nozzle.

Figure 5. - Variation of fuel flow with exhaust-nozzle area and rotor speed.



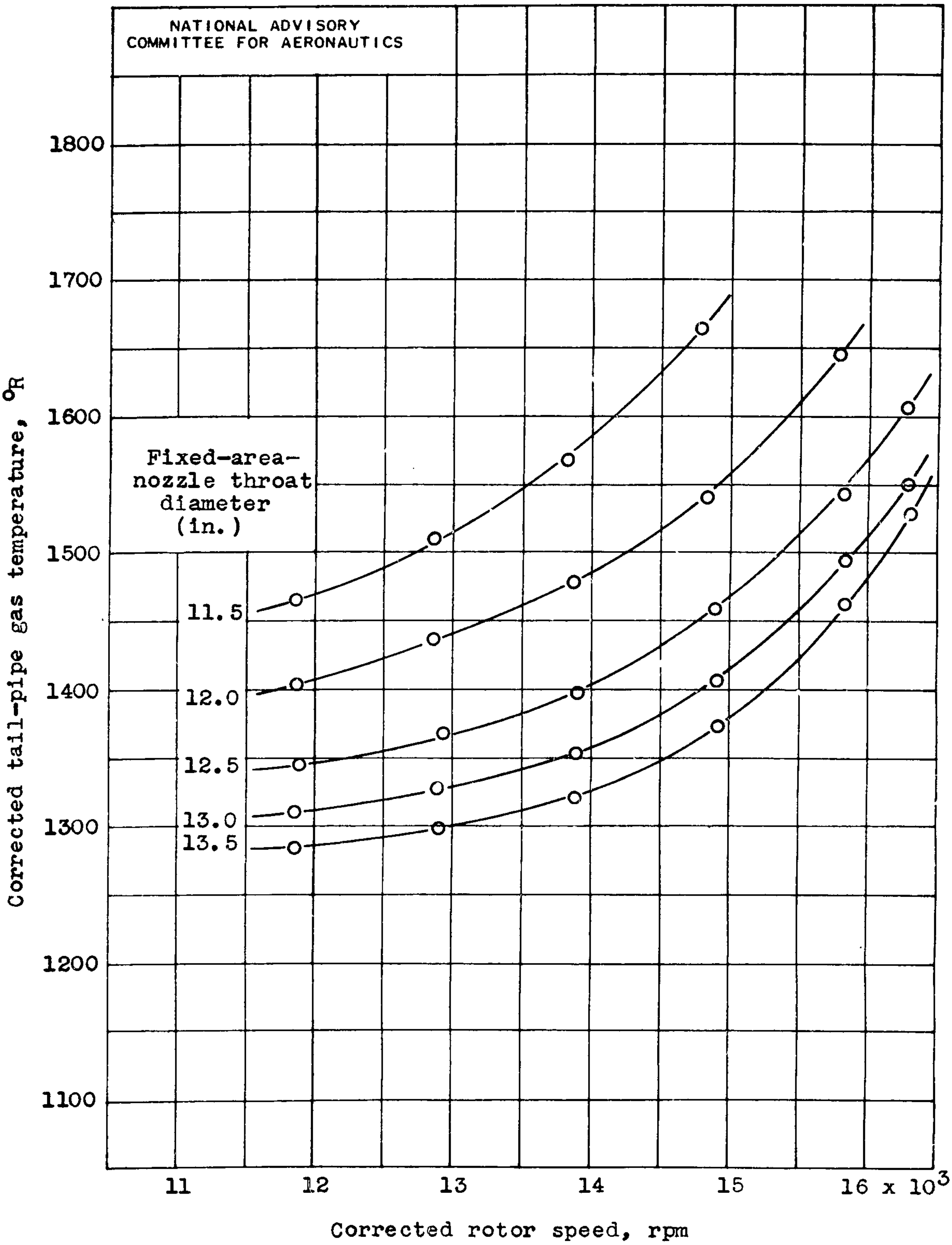

(b) Fixed-area nozzles.

Figure 5. - Concluded.




(a) Adjustable-area exhaust nozzle.

Figure 6. - Variation of tail-pipe gas temperature with exhaust-nozzle area and rotor speed.




(b) Fixed-area nozzles.

Figure 6. - Concluded.

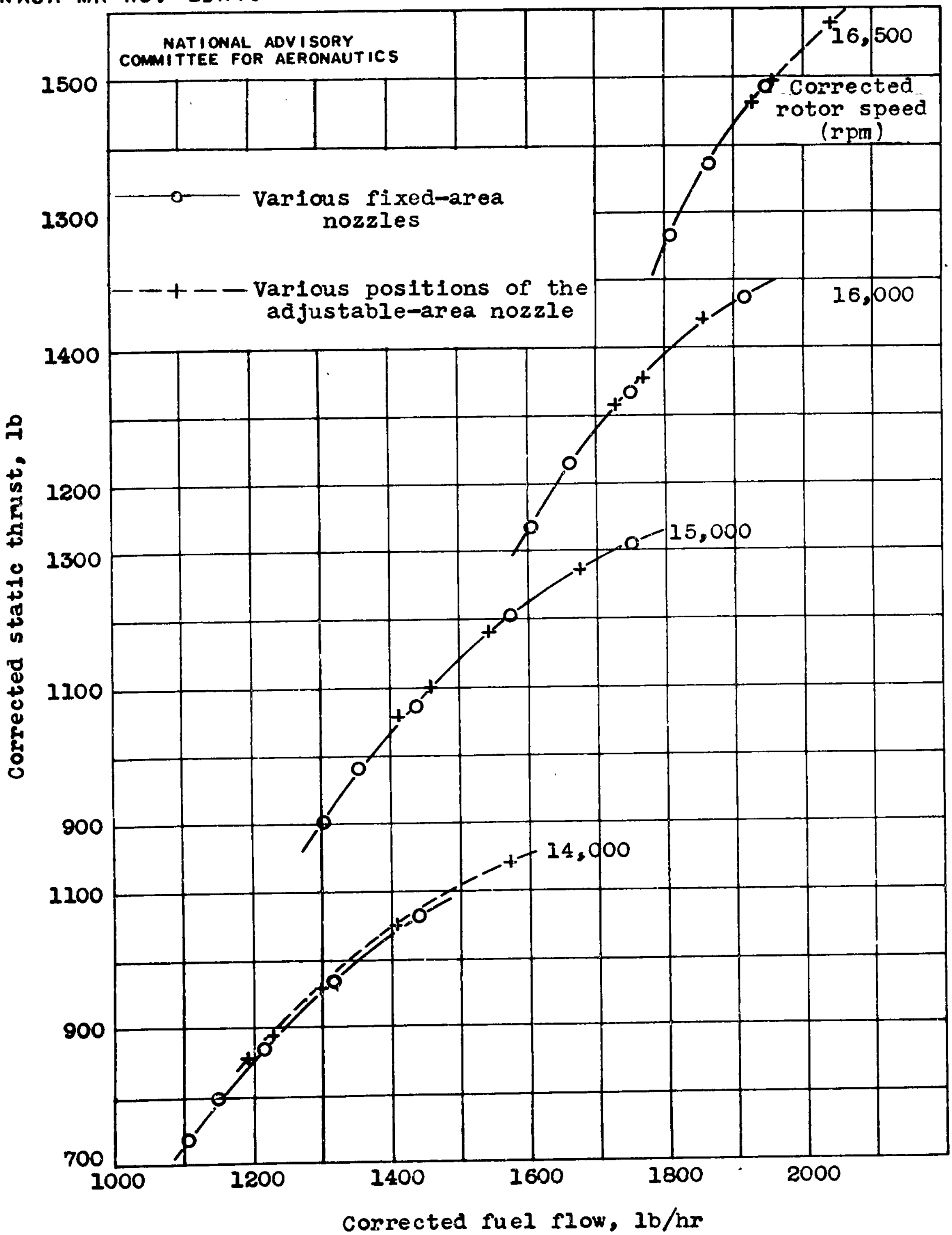



Figure 7. - Variation of thrust with fuel flow for constant rotor speeds. (Cross plot from figs. 4 and 5.)

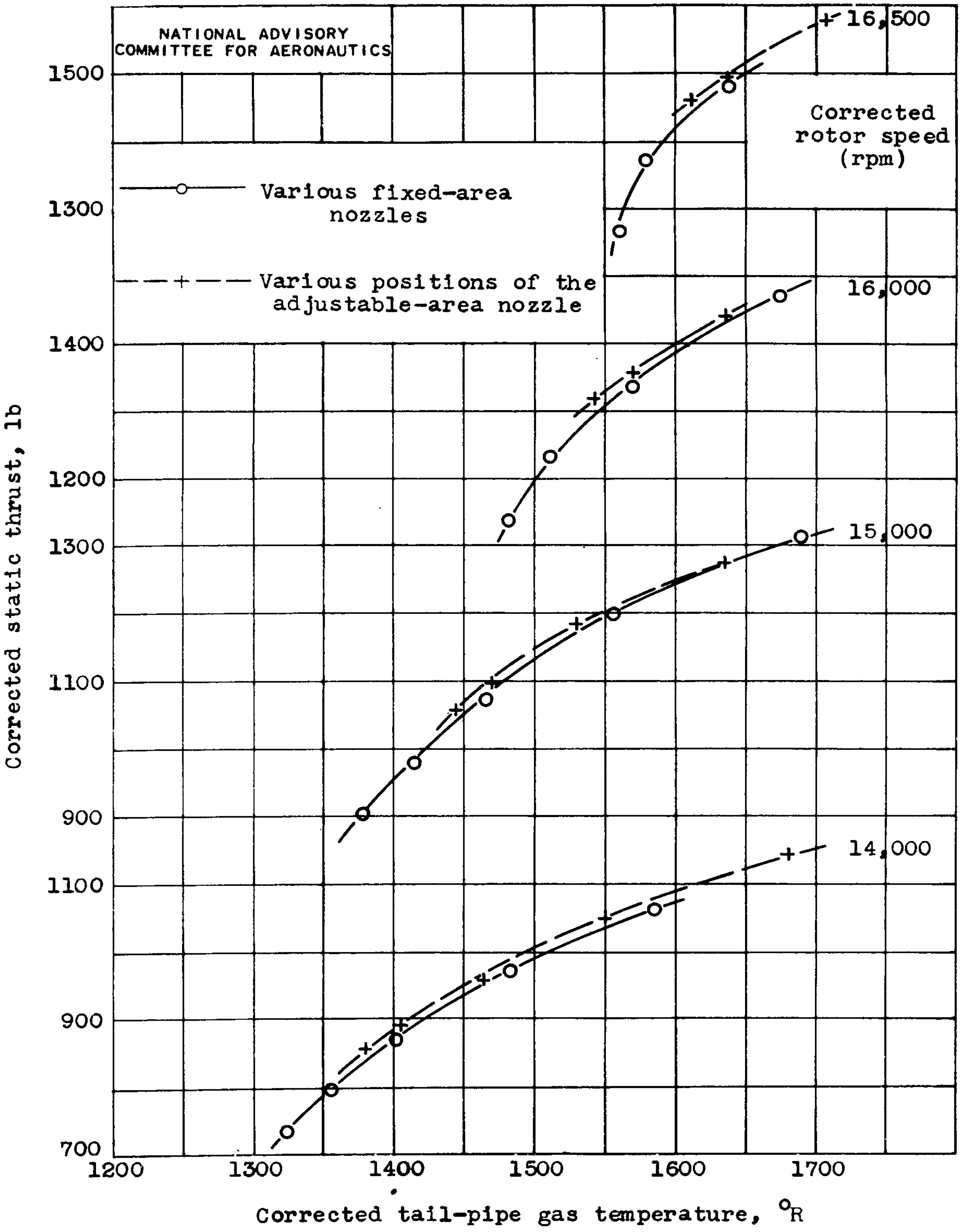



Figure 8. - Variation of thrust with tail-pipe gas temperature for constant rotor speeds. (Cross plot from figs. 4 and 6.)

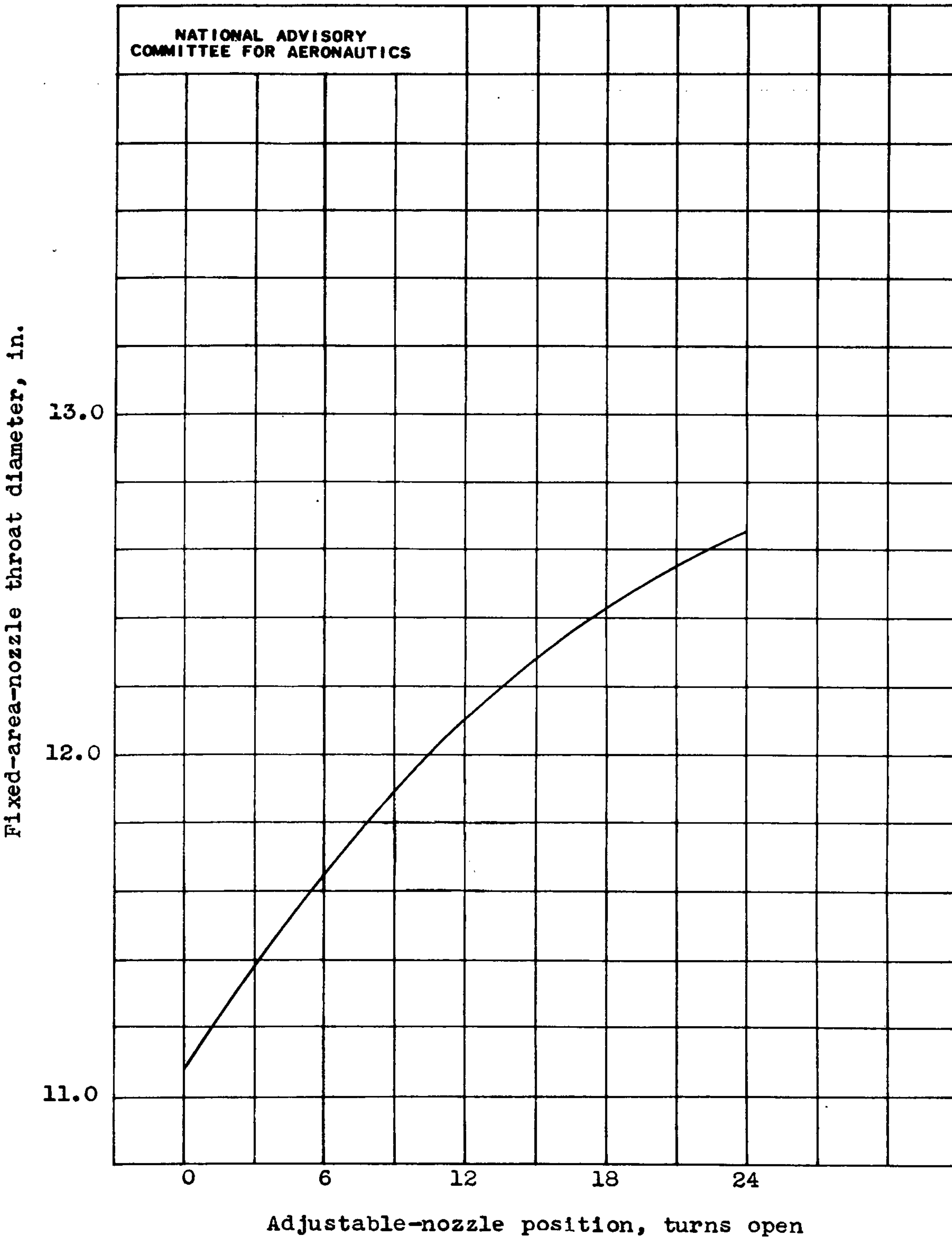



Figure 9. - Variation of equivalent fixed-area-nozzle throat diameter with adjustable-nozzle position. Rotor speed, 14,000 rpm.